# Fatigue Characterization Of Honeycomb Sandwich Panels With Small Defects

**A. ABBADI[a], M. HADJ MELIANI[b], C. TIXIER[c], J. GILGERT[c], Z. AZARI[c]**

a. ENSA, Equipe de mécanique et calcul Scientifique, Université mohamed 1 [er], BP 696, Oujda, Morocco, abbadi57@gmail.com
b. Laboratoire de Physique Théorique et Physique des Matériaux (LPTPM), FSSI, Université Hassiba Benbouali-Chlef-02000, Algeria, hadjmeliani@yahoo.fr
c. Laboratoire de mécanique, Biomécanique, Polymère, Structures (laBPS), Ecole Nationale d'Ingénieurs de Metz, 1 route d'Ars Laquenexy, 57070 Metz, France, azari@enim.fr

## Abstract

*The honeycomb sandwich panels are mostly used for their high stiffness, their good fatigue resistance and their low load ratios. In the last several decades, the sandwich structures have increasingly supplanted metals in many structural applications involving aircraft, aerospace, military vehicles, automobiles, civil infrastructure, medical devices, and sporting equipment. In order to characterize efficiently the honeycomb sandwich panels, the static behaviour does not seem to be sufficient and additional information about fatigue data properties is needed. This study presents an important experimental fatigue data for honeycomb sandwich panels with artificial defects and without defects. The results from the fatigue tests on honeycomb sandwich panels are compared to those of the aluminium alloy skin (the reference case). Experimental results showed that:*

*-The presence of defect has no influence on the static behaviour of the material.*

*-The lifetime of the L configuration is larger than in the W-direction.*

*-The lifetime of sandwich panels is very sensitive to drilling hole type defect than Brinell one.*

**Key Words : Honeycomb sandwich panels, static and fatigue behavior, drilling hole and Brinell ball defects**

## 1 Introduction

Honeycomb sandwich panel is composed by two different materials called the skin, and the core. The first one has a high elastic modulus and strength, and is thin. The second material has a quite important thickness but a very low density. In order to meet the ever growing request of lighter vehicles, high speed trains and ships, the transportation industry is engaged in the design and construction of structures quite different from the traditional ones, and as a consequence a lack of experiences concerning the strength of many structural details has become apparent. A correct use of these materials in different applications requires a better knowledge of their mechanical behavior: particularly, the fatigue behavior. Thus, even if the concept of the sandwich construction is not very new, there is a need for new research activities in order to provide the designers of sandwich structures with new reliable data.

The first study to characterize honeycomb sandwich panels without defects on two different types and different densities of the core under static and fatigue loading has been realized by abbadi et al. [1].

The static results on sandwich panels with aluminium and aramide fibres core have shown (Fig. 1) that the sandwich composite stiffness increases when increasing the core density and the load to failure increases with increasing cores densities. The sandwich panels with ramide fibres are almost more ductile than those made of aluminium cores. [2] studied a model for fatigue lifetime prediction based on the fatigue modulus concept (degradation of stiffness) which is proposed for core-dominated behavior. Both orientation cells (L and W) of honeycomb core sandwich have been studied by this model. The application of the exponential model gave a good result when the cells are in W direction. While for L direction exponential model was found to be less satisfactory than a third order polynomial function. Azouaoui et al. [3] investigated an experimental evaluation of impact fatigue damage in glass/epoxy composite laminate. The aim of this paper is to characterize honeycomb sandwich panels with two kinds of defects (Brinell ball, and drilling hole) on two types of honeycomb core (aluminium and aramide fibre) under fatigue loading. First, fatigue results of the characterization are compared to fatigue results of aluminium alloy skin which is the reference case. Second, Wöhler curve in the term of (load versus number of cycles) of honeycomb sandwich panels with and without defects is presented and discussed.

# 2 Experimental study

## 2.1 Description of material specimens

Honeycomb sandwich panels are delivered by EuroComposite (Luxembourg) and intended for the aeronautical, marine and automobile industry. The geometrical dimensions of the specimen are shown in Table 1. The faces of a thickness equal to 0.60 mm are made of aluminium (AlMg3 (5754)), the core structure is made from (3003) aluminium alloy (ECM) or aramide fibres (ECA) folded and glued together forming a hexagonal cell structure. The aluminium or aramide fibre (Nomex) honeycomb core is an opened cell with a density of 82 kg/m3 or 48 kg/m3 and 144 kg/m3 and a cell size of 6,4mm or 3.2 mm respectivelly. The geometrical and mechanical properties of the panels are depicted in Tables 2 and 3.

| $L$ | $b$ | $h$ | $h_c$ | $t_f$ | $L_1$ | $L_2$ |
|---|---|---|---|---|---|---|
| 500 | 250 | 10 | 8,8 | 0,6 | 210 | 420 |

Table 1: Specimen dimensions, unit: mm

| Young's modulus (MPa) | Failure strength (MPa) | Tensile strength (MPa) | Maximum elongation (%) |
|---|---|---|---|
| 70000 | 268 | 367 | 13 |

Table 2: Properties of sandwich aluminium facings (AlMg3(5754))

| Designation | Alu-Alu | Alu-Fibre | Alu-Fibre |
|---|---|---|---|
| Skin | Aluminium | Aluminium | Aluminium |
| Core | Aluminium | Aramide fibre | Aramide fibre |
| Cell size (mm) | 6,4 | 3,2 | 3,2 |
| Density (kg/m$^3$) | 82 | 48 | 144 |
| Shear resistance L-direction (MPa) | 2,4 | 1,32 | 3,5 |
| Shear modulus (L-direction (MPa)) | 430 | 51 | 128 |
| Shear resistance W-direction (MPa) | 1,4 | 0,72 | 2,2 |
| Shear modulus (W-direction (MPa)) | 220 | 30 | 94 |
| Compressive strength (MPa) | 4,5 | 2,1 | 15,2 |

Table 3: Core properties

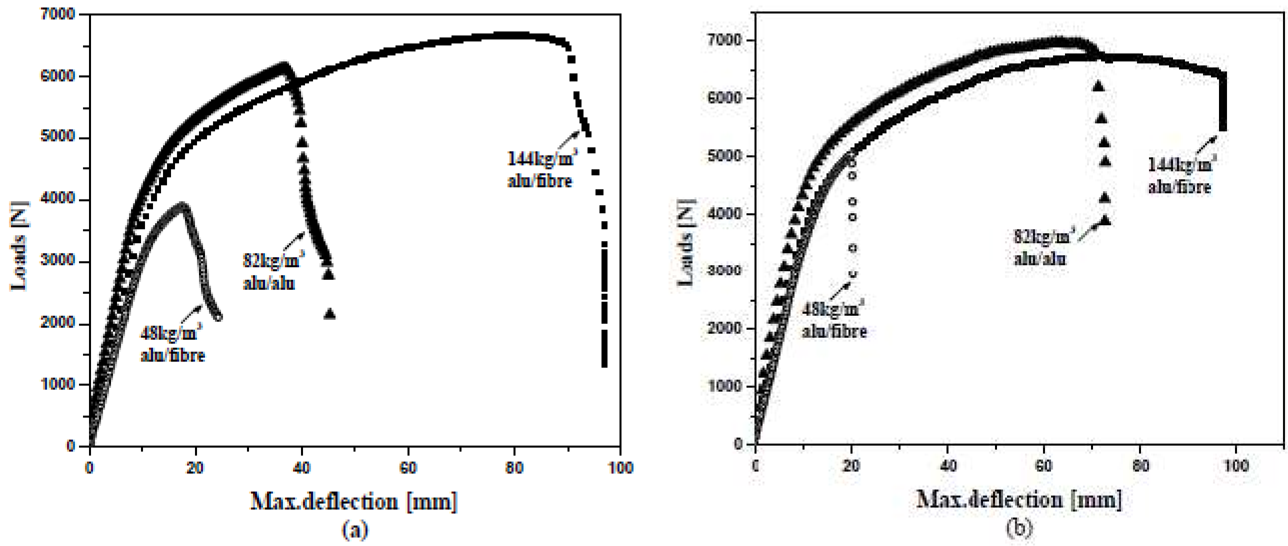


Figure 1: Evolution and comparison of the deflection according to the applied vertical load [2]:
(a) the W configuration
(b) the L configuration

The honeycomb sandwich panels, in aeronautics domain for example, may be subject to impact (bird, rock, dust, etc…). In this case, it is necessary to have some information on the influence of defect on the fatigue behavior of these sandwiches. To evaluate the defect influence on the fatigue lifetime of honeycomb sandwich panels, first a hemispherical defect is realized in the middle of the specimen. This defect is performed with a Brinell ball of a diameter equal to 2.5mm (Fig. 2). The indentation undergoes a load of 625N. Second, a hole defect type is realized in the middle of the specimen (Fig. 3). This defect is applied with a penetrator and has a diameter of 0.3mm. The defect sizes are chosen in compliance with those caused by an actual impact.

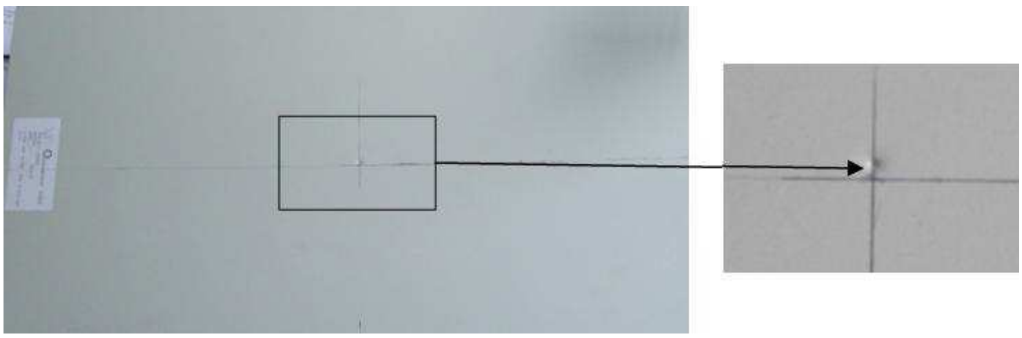

Figure 2: Hemispherical defect (type Brinell)

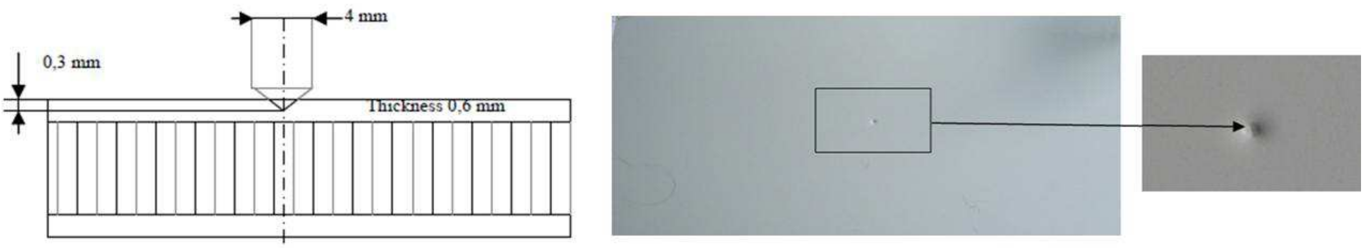


Figure 3: Drilling defect

Both static and fatigue tests on honeycomb sandwich panels with and without defects, two configurations core (L and W) (Fig. 4) and different densities were carried out through a four point bending testing fixture device. While in order to characterize the aluminium alloy skin under static and fatigue loading, specimens in alumunium have been machined from an aluminium (AlMg3 (5754)) palte (Fig. 5). The static and fatigue tests on aluminium alloy skin were performed using a tension test.

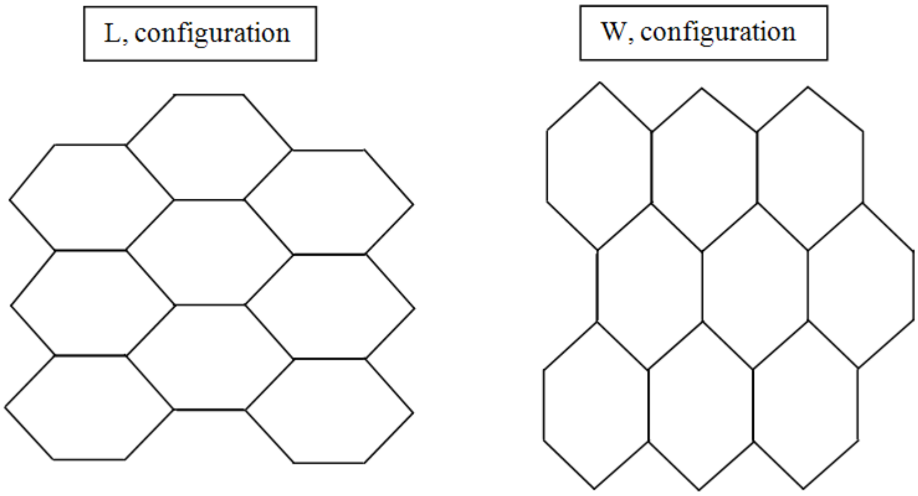


Figure 4: Cells configuration (L and W).

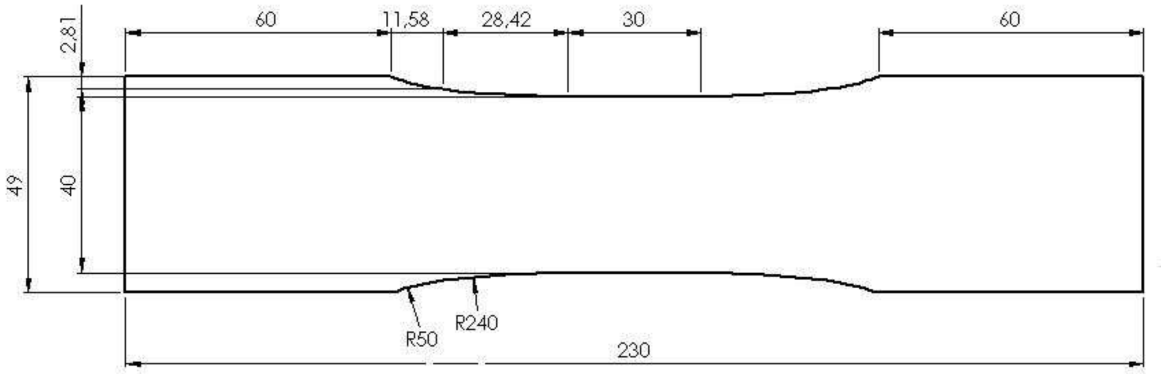


Figure 5: Aluminium specimen plan with a thickness of 0,6 mm

## 2.2 Static tests results

Static tests on aluminium alloy skin (AlMg3(5754)) were carried out at a constant displacement rate of 2 mm/mn in order to archive a quasistatic loading condition. The static tests were realized on a flat specimen with a thickness of 0,6 mm. The results are illustrated in Fig 6, and show that the ultimate tensile stress, yield stress and young modulus were equal to 249 MPa, 149 MPa and 67,000 MPa respectively. In addition, the experimental data are used to define the values of fatigue loading cycles.

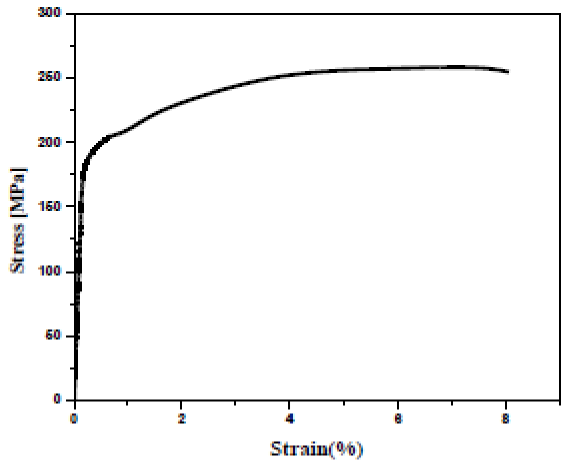


Figure 6: Typical stress–strain curve for 5754 aluminum skin alloys

To study the influence of defect on static behavior of honeycomb sandwich panels (alu/fibre aramide core, density 48 and 144 kg/m3 and L direction), static tests were carried out on specimens with drilling defect type. The results were compared to static results obtained on honeycomb sandwich panels without defect. Static experimental data of honeycomb sandwich panels with defect show (Fig. 7) that the presence of defect has no influence on the global static behavior of the material. The curves (Fig. 7) show that for both tests with and without defect the sandwich materials have a same ultimate load (5 kN for a core made from alu/fibre with a density of 48 kg/m3) and (7 kN for a same core (Alu/fiber) with a density of 144 kg/m3). However, the defect (type drilling) has no influence neither on the maximum ultimate load nor on the maximum deflection. The experimental data are also used to define the values of loading levels of fatigue testing.

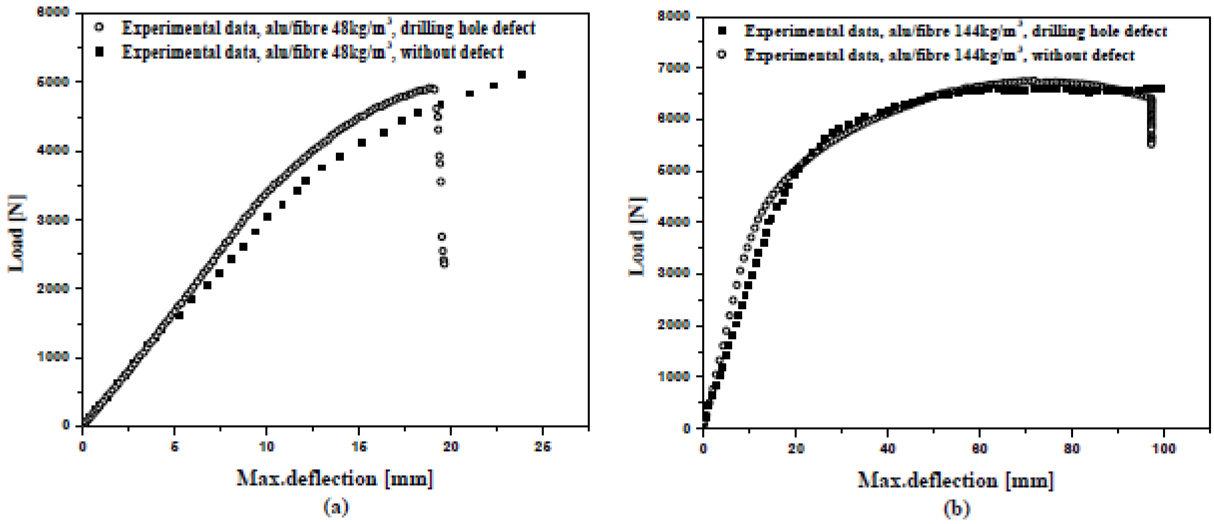


Figure 7: Comparison of static behavior between sandwich panels without defect and sandwich

panels with drilling hole defect

(a) density 48kg/m3 , L configuration, core made from aramide fibre

(b) density 144kg/m3 , L configuration, core made from aramide fibre

## 2.3 Fatigue tests Results

### 2.3.1 Comparison between sandwich panels without defect and aluminium alloy skin

Fatigue tests on sandwich panels with and without defects were performed at a room temperature under direct load control, while the load cycling amplitudes were chosen on the basis of the static test results. The waveform of cyclic loading was sinusoidal, and the frequency was set to 2 Hz. In all fatigue tests, the load ratio *R*, defined as the ratio of the minimum applied load ***Pmin*** to the maximum one ***Pmax*** of each loading roller, was set to 0.1. Fatigue data were generated at load levels **(*r*)** of 100%, 90%, 80%, 70%, 65% and 60% of the static ultimate load **(*P*ult)**. The fatigue life *Nf* was defined as the number of cycles corresponding to a drop of 50 % in stiffness of sandwich panel.
To characterize the aluminium alloy skin (reference case) tension-tension fatigue tests were performed. The test load is sinusoidal with a frequency of 20 Hz, and a load ratio of *R* = 0.1. The loading levels in the fatigue tests were determined according to the ultimate loads ***Pult*** obtained in the monotonic tests. The maximum applied loads in the fatigue tests were selected from 64% to 80% ultimate loads. The fatigue life of the specimens is characterized as the number of cycles to ultimate failure (*Nf*). The experimental results obtained from fatigue tests on aluminium alloy skin (5754) were compared with values reported in literature (Fig. 8). At higher fatigue load aluminium alloy (7050) [4] has better fatigue strength than aluminium alloys (6N01) [5], (5754) and (5052-H32) [6] respectively. Moreover, the curve of aluminium alloy skin (5754) is located symmetrically between the aluminium alloy curves 7050 (upper bound) and 5052 (lower bound).

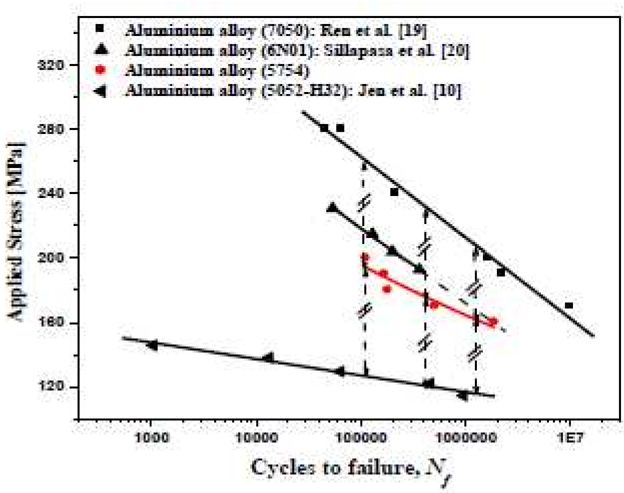


Figure 8: Tensile stress-number of cycles curves for different aluminium alloy

The experimental fatigue data reported in Figs 9 and 10, shows that the L configuration of investigated panels have a better fatigue life at high values of applied loads respect to W configuration. While at low values of applied loads the W configuration has a better fatigue strength than L configuration. The experimental fatigue results of the aluminium alloy skin and sandwich panels without defect for a density of aluminium core (82kg/m3) for both directions (L and W) are compared. The fatigue curves in terms of load level versus the number of cycles, shown in (Fig. 9), illustrate a qualitative comparison between the fatigue lifetime of alumunium alloy skin and sandwich composites made of aluminium core. At constant load level, the lifetime of the L configuration is larger than in the W-direction for the sandwich panel while that of aluminium alloy skin is found to be always lower. Notice that the L direction is more resistant than W direction and aluminium alloy skin. After extrapolation of the two (*L* and *W* configurations) fatigue curves, one notices the intersection of these curves for a load of 3900 N (Fig. 9) and a lifetime of $3\times10^6$ cycles. While the comparison between the experimental fatigue results of the aluminium alloy skin and sandwich panels without defect for two densities of aramide fibers core (48 kg/m3 and 144 kg/m3 ) and for both cell directions (L and W) is illustrated in Fig 10.

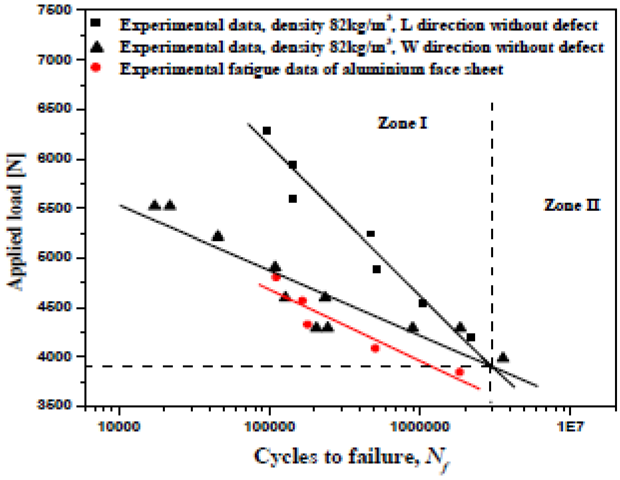


Figure 9: Comparison of behavior between sandwich panels and aluminium alloy skin.

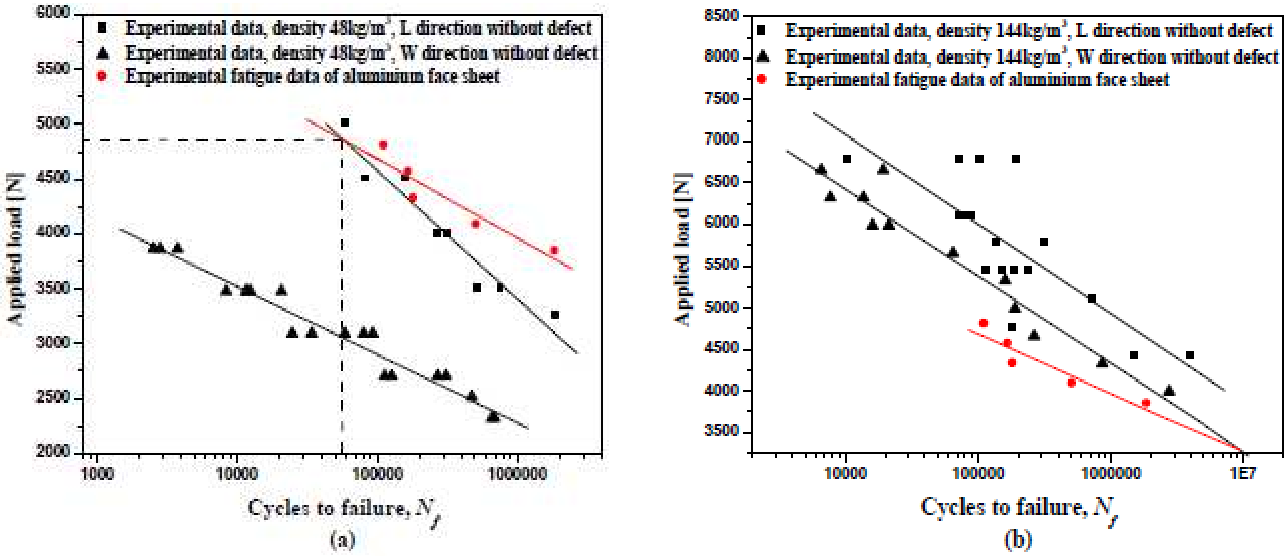


Figure 10: Comparison of fatigue behavior between sandwich panels (aramide fibres core) and aluminium alloy skin
(a) the density: 48 kg/m3
(b) the density: 144 kg/m3

The fatigue experimental data show that for the sandwich panel with a core density of 48 kg/m3, the lifetime of the L configuration is larger than in the W-direction while that of aluminium alloy skin is found to be always higher (Fig. 10a). In addition, the aluminium alloy skin is more resistant than L direction and W direction. This original result shows that from a certain value of sandwich core density, the fatigue behavior of skin sheet is far better than sandwich panel. As shown in (Fig. 10a) after extrapolation of the two (L configuration and face sheet) curves, the intersection of these curves for a load of 4875 N and a lifetime of $5.8\times10^4$ cycles, it is observed that the fatigue behavior is reversed, i.e. the life time of the L configuration is larger than face sheet. While for a density of 144 kg/m$^3$, the lifetime of the L orientation cells is larger than W direction and aluminium alloy skin (Fig.10b).

### 2.3.2 Comparison between sandwich panel with and without defect and aluminium alloy skin

The number of fatigue tests carried out on the sandwich panels with the two kinds of defect (Brinell and drilling hole) was limited to a small number of specimens. However, the fatigue study on sandwich panels with defect was an exploratory approach in order to evaluate the effect of the presence of defect on the fatigue life. The experimental fatigue results of the aluminium alloy skin and sandwich panels with defect (type Brinell) for a density of aluminium core (82 kg/m3) and for both cells direction (L and W) are compared. The curves in Fig. 11a show that the lifetime of the L configuration is larger than in the W-direction for the sandwich panel while that of aluminium alloy skin is found to be always lower. Fatigue tests results on sandwich panels with defect (type Brinell) for a density of aramide fibres core (144 kg/m3) and for both configurations (L and W) exhibit the same behavior as that of sandwich panels with aluminium core (82 kg/m$^3$). Furthermore, the lifetime of L configuration (Fig. 11b) is larger than in W direction and aluminium alloy skin. This result confirms that whatever the sandwich panel with or without defect the lifetime of L direction is more resistant than W one. To investigate the effect of drilling hole defect on the lifetime of sandwich panels made from aluminium core (82 kg/m3), a typical defect of 0.3mm of diameter was machined in the centre of sandwich panels.

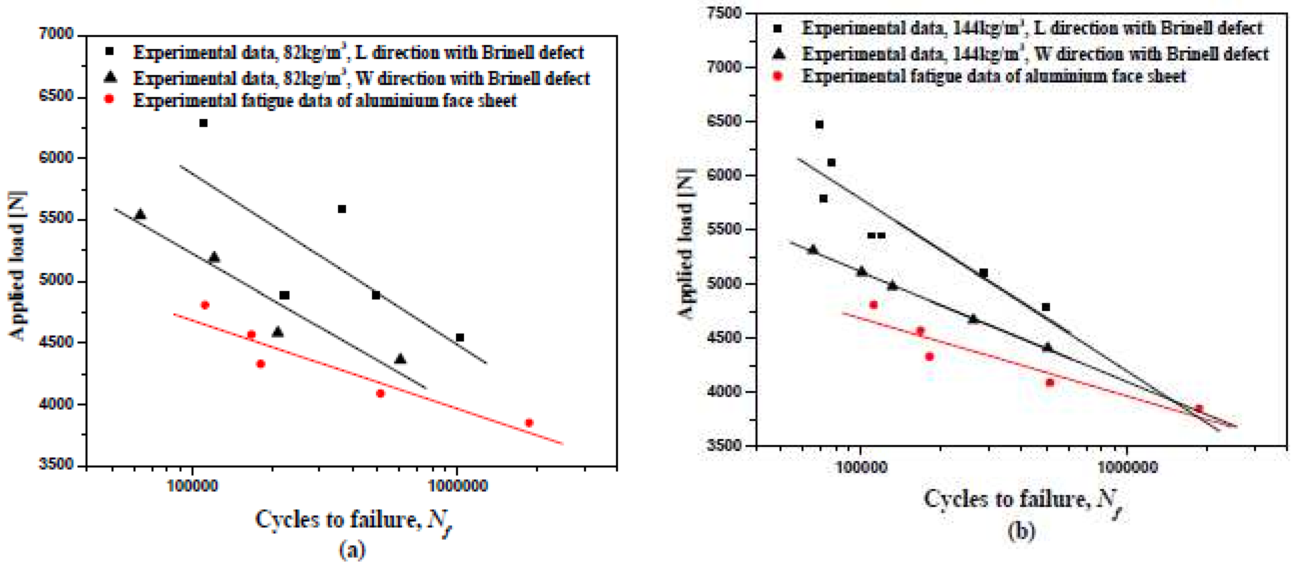


Figure 11: Comparison of behavior between sandwich panels with defects and aluminium alloy skin
(a) aluminium core (density: 82kg/m$^3$)
(b) aramide fibres core (density : 144kg/m$^3$)

The fatigue curves shown in Fig 12, illustrate a comparison between the fatigue lifetime of sandwich composites panels with two types of defect (Brinell and drilling hole), sandwich composites panels without defect and aluminium alloy skin. This comparison is made in the case of sandwich panels with aluminum core (82 kg/m3) and in the L configuration. The fatigue experimental data (Fig. 12) shows that the lifetime of aluminium alloy skin is always lower than sandwich panels without defect, with defect type Brinell and drilling hole respectively. However, it can be concluded that the lifetime of sandwich panels is very sensitive to drilling hole defect than Brinell one.

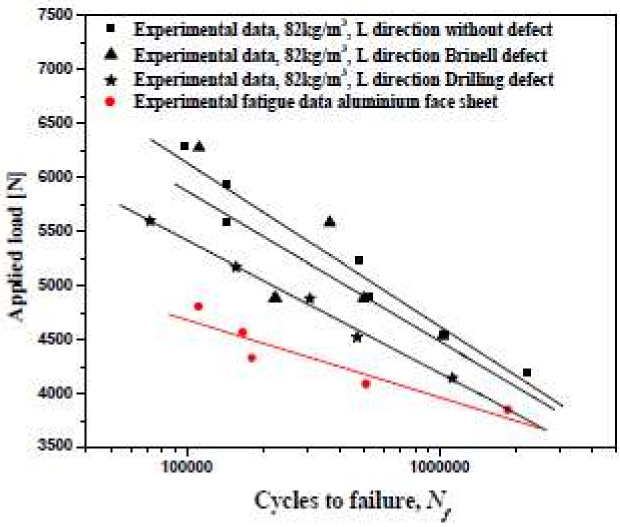


Figure 12: Comparison of fatigue behavior between aluminium face sheet, sandwich panels without
defect and sandwich panels with Brinell and drilling defects (aluminium core, density 82kg/m3).

# 3 Fatigue failure mode

The following discussions regarding the fatigue failure processes are only based on visual inspection of the free sides of the panels. However, the fatigue bending tests produces various collapse modes for panels with the same density, depending on the applied load level and the orientation of cells (L or W). The two dominant collapse modes observed are facing crack and indentation modes. During fatigue bending tests other collapse modes were observed. In addition to indentation and cracking face collapse modes, sandwich structures made of aramide fibres cores density 48 kg/m$^3$ for both W and L configurations failed in shear with a crack propagating through the thickness of the core (Fig. 13). The crack propagation is always in the diagonal direction in the case of the W configuration and horizontal for the L one. In both cases, cracks or micro cracks appear before any macro size crack is formed. We also noticed a subsequent shear buckling (Fig. 13) of the vertical cell walls in the center region between the inner and outer support from the first load cycles as well as the formation of several clusters of small horizontal cracks in the cell walls formed within separate cell as shown in Fig. 13.

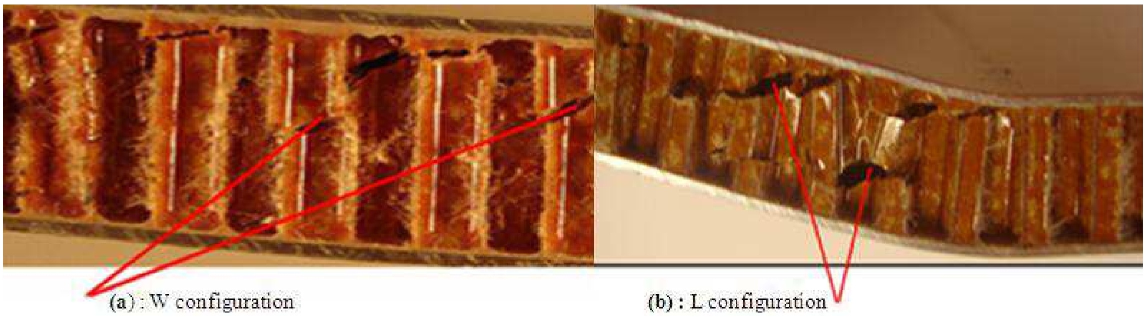


Figure 13: Failure modes of the aramide fibres cores, density 48kg/m$^3$

While for sandwich structures made with the same core (aramide fibres) for a density of 144 kg/m$^3$, several collapse modes appear in the W configuration: buckling for the upper skin, core punching, core/skin debonding and core shear between the applied load support and fixed one. However, the debonding collapse mode between the core and the lower skin (Fig. 14) and the core shear collapse mode between the applied load support and fixed one are shown respectively in Figs 14 and 15.

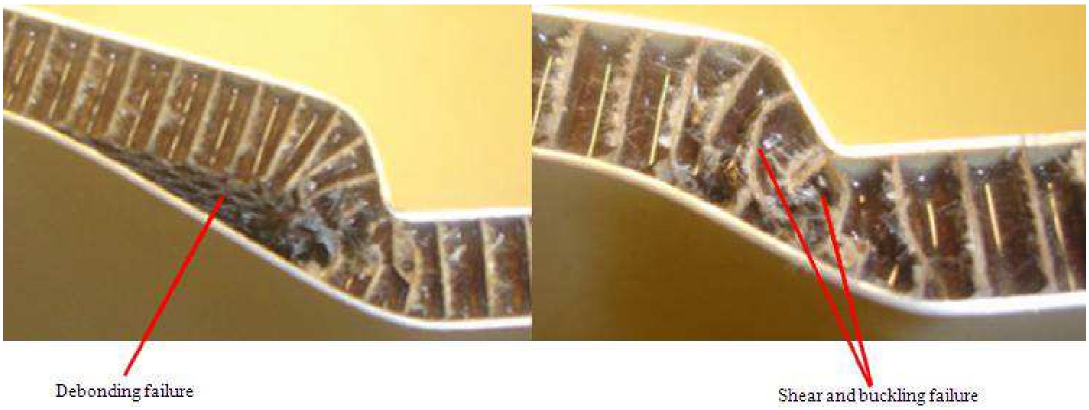


Figure 14: Shear and growth cracks failure modes of the aramide fibres cores, density 144 kg/m3, in the W direction

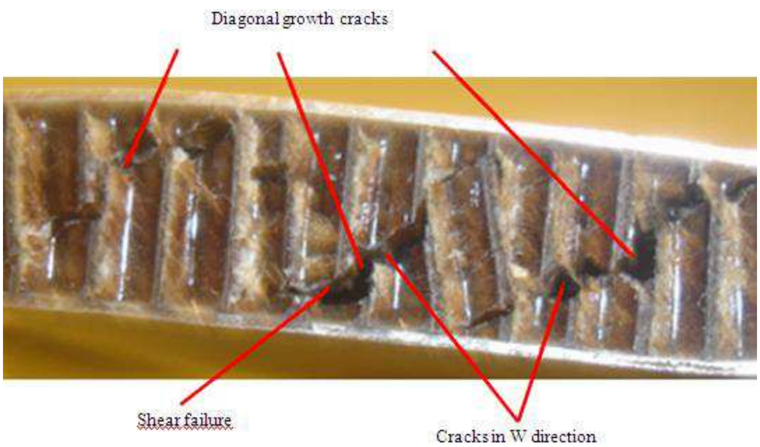


Figure 15: Shear and growth cracks failure modes of the aramide fibres cores, density 144 kg/m$^3$, in the W direction

The fatigue failure processes of composites sandwich panel with defect is based on the visual inspection. The experimental observations (Fig.16) show that the two kinds of defects (Brinell and drilling hole) lead to the same collapse mode (lower face cracking). In addition, the crack initiates in the defect then propagates through the width of the specimen and no damage occurs through the core of the sandwich composite material.

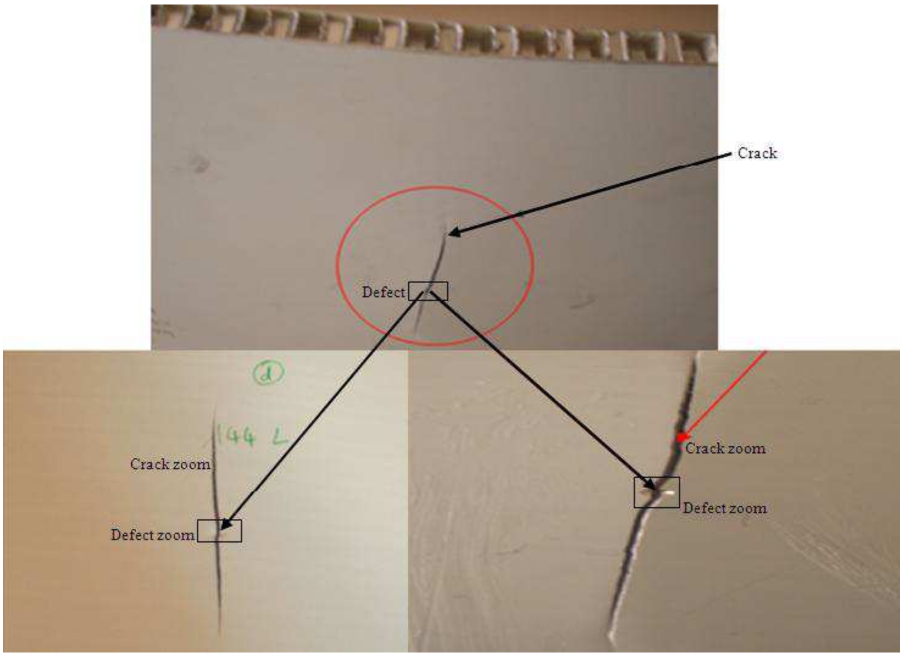


Figure 16: Collapse mode of sandwich panels with defect

# 4 Conclusions

This research experimentally studied fatigue data in four-point bending on two kinds of sandwiches; one with presence of defect and the other without defect. From the obtained experimental data, it is possible to draw some conclusions on the behavior of investigated sandwich panels:

**(1)** Static experimental data have shown that the presence of defect has no influence on the static behavior of the material.

**(2)** Fatigue experimental data have shown that the lifetime of the L configuration is larger than in the W direction. It was found that for sandwich panel with aramide fibre core (density 48 kg/m3), the fatigue behavior of face sheet is far better than sandwich panel.

**(3)** The lifetime of sandwich panels was more sensitive to drilling hole type defect than Brinell one.

# 5 REFERENCES

[1] S. Belouettar, A. Abbadi, Z. Azari, R. Belouettar, P. Freres, Experimental investigation of static and fatigue behaviour of composites honeycomb materials using four point bending tests, Compos Struct87 (2009) 265-73.

[2] A. Abbadi, Z. Azari, S. Belouettar, J. Gilgert, P. Freres, Modelling the fatigue behaviour of composites honeycomb materials (Aluminium/aramide fibre core) using four-point bending tests, Int J Fatigue32 (2010) 1739-47.

[3] K. Azouaoui, Z. Azari, G. Pluvinage, Evaluation of impact fatigue damage in glass/epoxy composite laminate, Int J Fatigue32 (2010) 443-452.

[4] X. Ren, L. Zhang, Y. Chen, F. Sun, W. Zhang, L.Lin, Y. Wang, Tensile and fatigue properties of 7050 aluminum alloy axle box used for high speed train, Procedia Engineering27 (2012) 914-922.
[5] K. Sillapasa, S. Surapunt, Y. Miyashita, Y. Mutoh, N. Seo, Tensile and fatigue behavior of SZ, HAZ and BM in friction stir welded joint of rolled 6N01 aluminium alloy plate, Int J Fatigue32 (2014) 160-170.
[6] YM. Jen, HB. Lin, Temperature-dependent monotonic and fatigue bending strengths of adhesively bonded aluminum honeycomb sandwich beams. Materials & design45 (2013) 393-406.